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IMPROVING PROJECT MANAGEMENT MONITORING AND CONTROL: A SIMULATION APPROACH

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ABSTRACT

There is a broad category of Operations Management problems having to do with the management of project type operations. Such operations are typically illustrated by the example of some large-scale, one-time activity such as the design and production of a new prototype machine, the construction of a new facility, or the design and manufacturing of a new system to serve a specific or general propose. The basic approach to all project scheduling is to form an actual or implied network that graphically portrays the tasks and milestone in the project. There are several techniques evolves in the late 1950s for organizing and representing this basic information. Best known today are PERT (Program Evaluation and Review Techniques) and CPM (Critical Path Method). Other network techniques such as PERT/Cost, GERT and Decision CPM are largely extension and modifications of these original two. It is well known and reported in the literature that CPM is best used for situations with a deterministic nature; on the other hand, PERT is best used for stochastic situations. However, although PERT is able to deal with uncertainty in activities times by using three point estimates (optimistic time, most likely time and pessimistic time), the estimate of activity times are clearly subjective and rely solely on judgment. This research paper and through a real life construction project propose a Monte Carlo simulation approach to deal with the short coming problems inherited in the PERT. The results obtained from our comprehensive simulation approach shows that project managers are able to estimate the probability of project completion time and thus allocate contingency plan for the project. In addition, project managers are able to consider the possibility of sub-critical path(s) that might eventually become the critical path as the project progresses through time. The obvious contribution of this research work is the opportunity that provides for project managers to carefully examine their estimation of the project activities times and the sub-critical path(s) leading to a much improved approach for monitoring and controlling the project.

Keywords: Operation Management; Project Management; PERT; CPM; Monte Carlo Simulation

INTRODUCTION

Project management is a relatively pure form of management. It provides people with a powerful set of tools that enhances their ability to plan, implement, and manage activities for the purpose of achieving a specific objective (Gray and Larson, 2008). Project management encompasses a lot of aspects, and numerous “tools” have been developed to help project managers in coping with the complications inherent in the performance of their duties. The most common utilized project management tools involve the modeling of a project as a network. Among the two well known methods developed for project scheduling are the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT). These scheduling methods had been used extensively in many disciplines like engineering, research and development, business planning, healthcare activities and even taught widely in project management academic courses. It is not surprised to see that almost all project management software packages were embedded with CPM and PERT in their project scheduling tool options.

However, CPM and PERT are not perfect in dealing with project scheduling problems. Because of the limitations CPM and PERT holds, simulation is seemed to be a promising tool to enhance the capability of the existing project scheduling tool (Douglas, 1978). The use of simulation as a method for the analysis of project networks was initiated by Van Slyke (1963). Since then, a lot of new simulation procedures have been developed for application in project management. Diamantas *et al.* (2007) compared the capabilities of PERT and Monte Carlo Simulation and addresses the incorporation of project risk management into the two approaches. Most recently, a paper from Kirytopoulos *et al.* (2008) had validated the superiority of simulation over PERT and aims to highlight the significance of historical information as well as the distribution selection in activity duration estimating, by contrasting the various outcomes of scenarios when historical information is or is not used. Various disciplines and industry has been implementing simulation as a scheduling tool in project management although it is still limited. Badri *et al.* (1997) had developed a simulation model for R&D planning stages in a major petroleum company. Dukić et al. (2007) has presented a management model for construction projects based on computer simulation. Thus the aim of this paper is to utilize simulation in order to provide the project managers a much improved approach for monitoring and controlling the project.

The remainder of the paper is organized as follows: The next section provides a description of the problem being studied. Next, the solution methodology followed in this paper is presented in detailed, followed by a thorough result and discussion. The last section concludes the overall research of this paper.

PROBLEM DESCRIPTION

The presented case study was a small scale construction project conducted in Malaysia, as shown in Appendix A, obtained from consultation firm which helps developer to design the project layout for tender purposes. It dealt with the construction of a warehouse, where it involves 31 activities.

The project activities shown in Appendix A can be easily modeled in a network by entering the activity, duration and its precedence relationship in Microsoft Project. The network was able to visualize the activities realization in its precedence relationship, the critical path and the total project completion time. The project network for this problem is illustrated in Figure 1.

Once the project manager developed the project plans and the activities, he/she need to answer these questions which constitute a general project management problem. These questions are:

1. How accurate/reliable the estimate produced by Microsoft Project in terms of total project completion?
2. Is there a chance for an activity which is not in the critical path becoming a critical activity and thus changing the original critical path?

Although the consultation firm utilizes Microsoft Project by using CPM, the capability of Microsoft Project is somehow limited when uncertainty is taken into consideration. In addition, construction projects are complicated in nature and subject to few uncertainties, which originate from the unique characteristics of each project, the variety of resources and activities, and some external factors as well. When these uncertainties are incorporated in each of the activities, the critical path and the total project completion time is also become uncertain. Thus, simulation is introduced to understand the project activity uncertainties and thus management may enhance their decisions.

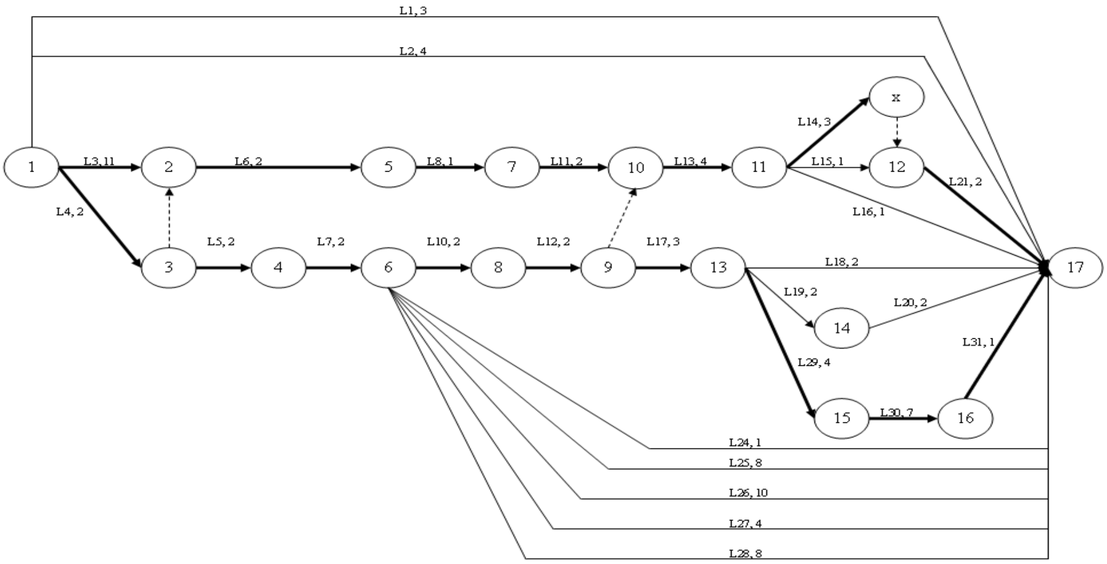

Figure 1: The figure shows an Activity on Arrow (AOA) network visualizing the project activities according to their precedence relationship as developed in Microsoft Project.

Notes: Red arrow (→) indicates critical activity.
Normal arrow (→) indicates non-critical activity.
Dashed arrow (- - - →) indicates dummy activity.
L3, 11 represents activity L3 with mean activity duration of 11 weeks.

SOLUTION METHODOLOGY

In order to provide a solution to the problem described earlier, two simulation scenarios will be used to answer the questions posed in the problem description. However, the model and scenario assumptions should be stated as the following:

1. Each activity was normally distributed and mutually independent.
2. The estimated duration of the activity was equal to the mean of the activity duration.
3. The standard deviation of each activity was randomly sampled from 1 to 2 for activity durations of 9 weeks and below; for activity durations of 10 weeks and above, the standard deviation would be 3.
4. All negative values were ignored in sampling the normally distributed activity duration.
5. The maximum of each activity duration being sampled was given by $\mu + 5\sigma$, where μ represents the mean of the activity duration and σ represents the standard deviation of the activity duration (Refer to Table 1).

Table 1: Activity duration parameters.

Actv	Mean, μ	Std Dev, σ	Min	Max, $\mu+5\sigma$
L1	3	2	0	13
L2	4	2	0	14
L3	11	3	0	26
L4	2	2	0	12
L5	2	2	0	12
L6	2	1	0	7
L7	2	1	0	7
L8	1	2	0	11
L9	1	1	0	6
L10	2	2	0	12
L11	2	1	0	7

Actv	Mean , μ	Std Dev, σ	Min	Max, μ +5 σ
L12	2	1	0	7
L13	4	1	0	9
L14	3	1	0	8
L15	1	1	0	6
L16	1	1	0	6
L17	3	1	0	8
L18	2	2	0	12
L19	2	1	0	7
L20	2	2	0	12
L21	2	2	0	12
L22	8	1	0	13
L23	8	2	0	18
L24	1	2	0	11
L25	8	2	0	18
L26	10	3	0	25
L27	4	2	0	14
L28	8	1	0	13
L29	4	2	0	14
L30	7	1	0	12
L31	1	2	0	11

Notes: Table above shows the parameters defined for each activity's duration and its minimum and maximum value to be sampled in a normal distribution.

The first scenario was to estimate the probability distribution of project completion time. The duration of each activity is normally distributed according to the parameters being defined which are the mean, standard deviation, minimum and maximum of the activity duration. After that, the time in each node in the project network reached is computed according to the precedence relationship of each activity.

Scenario 2 is dealing with determining the probability that an activity is critical. This scenario is done by duplicating the simulation model developed in the first scenario but with some adjustment i.e. by increasing the activity's length by a small amount of time. There will be 31 simulations and for each simulation, only 1 activity will be increase by a small amount of time on each simulation run. If the project completion time is increased by the same amount of time, it implies that the activity is critical.

The authors have used an off-shelf simulation package that can be embedded in Ms Excel. The simulation model was developed so that it generates two results, the probability distribution of project completion time and the probability that an activity is critical. Once the simulation model was fully developed, the simulation ran for 1000 times and the results were recorded into Ms Excel spreadsheet.

RESULTS AND DISCUSSIONS

For the first scenario, the authors reported that the simulation results indicate that there is a chance the project completion time will exceed the mean project completion time or a chance the project will complete earlier than the mean project completion time. The results of the simulation model in estimating the probability distribution of project completion time are presented in Figure 2 and Table 2.

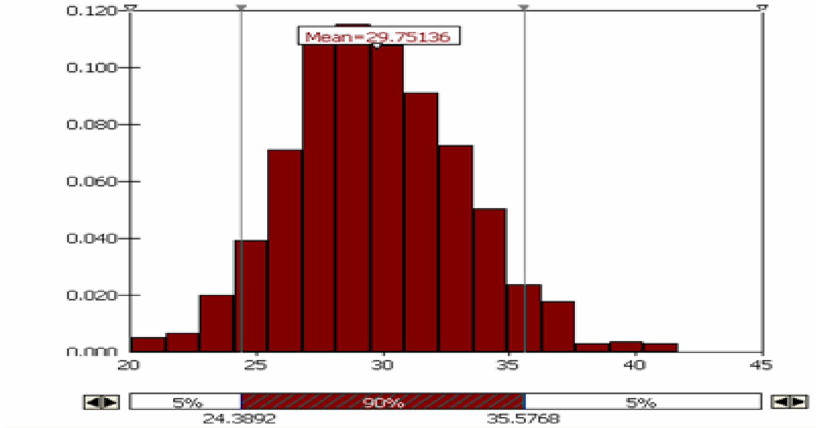

Figure 2: The figure shows the probability distribution of the project completion time using simulation in scenario 1. Examining Figure 2 indicates that approximately 90% of the project completion times lies between 24 days and 35 days with the mean project completion time of approximately 30 days.

Table 2: Percentiles of project completion times.

Percentile	**Project Length (days)**	**Percentile**	**Project Length (days)**
5th	24.38919	55th	30.10376
10th	25.53228	60th	30.49598
15th	26.2635	65th	30.92708
20th	26.91772	70th	31.42144
25th	27.36941	75th	31.93502
30th	27.86907	80th	32.68281
35th	28.29995	85th	33.34961
40th	28.64036	90th	34.21607
45th	29.10377	95th	35.57676
50th	29.56332		

Notes: The table above shows the percentiles of project completion time. For example, there is a 30% chance that the project will exceed 31 days and there is a 20% chance that the project will finish in approximately 27 days.

For the second scenario, the authors were able to generate the probability that an activity is critical. The activities which lie in the critical path had significantly higher probability than other non-critical activities. The results of determining the probability that an activity is critical are presented in Table 3.

Table 3: Estimation of probability that activities are critical.

Activity	**Probability of Being Critical**	**Activity**	**Probability of Being Critical**
L1	0	L17	0.6
L2	0	L18	0
L3	0.4	L19	0
L4	0.6	L20	0
L5	0.6	L21	0.4

Activity	Probability of Being Critical	Activity	Probability of Being Critical
L6	0.4	L22	0
L7	0.6	L23	0
L8	0.4	L24	0
L9	0	L25	0
L10	0.6	L26	0
L11	0.4	L27	0
L12	0.6	L28	0
L13	0.4	L29	0.6
L14	0.36	L30	0.6
L15	0.04	L31	0.6
L16	0		

Notes: The table above shows the estimation of probability that activities are critical. For instance, activity L29 which lie in the critical path had a probability of 0.6 but activity L27 which is does not lie in the critical path had a probability of 0. However, for activity L15 which do not lie in the critical path had a 0.04 chance to become a critical activity. This implies that non-critical activities had a chance in becoming critical and the original critical path identified through CPM may change.

As compared to the results obtained from Microsoft Project, the results were more optimistic as it does not account for any uncertainty. While Microsoft Project can give a single date for the project completion and critical path based on slack calculation, on the other hand, through simulation, it was able to yield unbiased project completion estimates by giving a range of project completion times and the probability that an activity is critical. This is useful for management to set aside a contingency plan in case of any delay and focus attention to activities which have high probability in becoming critical. It should be note that the correlation between the probability of an activity lies in the critical path and slack as calculated using CPM is weak

However, one of the most important thing when dealing with simulation in project scheduling is the information that being fed into it. In this study, the authors are dealing with defining the right distribution for the modeling of an activity’s duration. Right distribution mean the most appropriate distribution used to model the duration of a project’s activity based on personal experience and historical information (Kirytopoulos *et al.*, 2008). Thus, project manager must be wise in choosing probability distribution to run the simulation model. For simplicity purpose of this study, the authors only assume that all the activities are normally distributed.

CONCLUSION

Project management is a very important discipline that determines the success and competitiveness of an organization. It has been extensively used in the fields of civil engineering, defense, aerospace engineering and product development. Although there are many off-shelf software packages development in the required network, but one of the biggest challenge of the ready made software is the fact that activity time is based on judgment which in the opinion of the author is a drawback since it increases the risk and could be costly.

On the other hand, simulation is a powerful approach for investigation some scenarios that a management may take, unfortunately, it is not widely used yet in project management. The authors intend to investigate how simulation can be used to enhance management decisions associated with activities time duration and the estimation of the probability that an activity is in fact a critical activity that deserves the project engineering manager attention. The results presented by this paper proved that simulation was able to produce a more reliable estimate and on the other hand it can better handle uncertainty in project scheduling in which Microsoft Project is incapable of.

An interesting area for future research is the development of guidelines on how to select suitable and more accurate probability distribution for modeling the duration of the project activities, currently, the authors are working in that direction.

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APPENDIX

Appendix A: List of activities and their predecessors and the duration of each activity in the construction project.

Activit	Description	Predecessor(s)
L1	Preliminaries	-
L2	Earthwork (cut & fill)	-
L3	External rc. Retaining wall	-
L4	Pilling works	-
L5	R.C. pile cap	L4
L6	Stump	L3,L4
L7	Ground Beam	L5
L8	Ground Floor Slab Works	L6,L7
L9	RC Column	L7
L10	Suspended RC Beam & Slab	L7
L11	Steel Structure Work	L8, L9
L12	Roofing Work	L10
L13	Wall	L11,L12
L14	Wall Finishing	L13
L15	Floor Finishing	L13
L16	Door & Window	L13
L17	Drain Surrounding Building	L12
L18	Apron & RC Ramp Work	L17
L19	Sanitary & Plumbing	L17
L20	S&P Finishing Work	L19
L21	Painting Work	L14, L15
L22	Electrical & Telephone Installation	L12
L23	Fire Fighting Installation	L12
L24	Landscaping	L7
L25	Weight Bridge Office	L7
L26	TNB Sub-station	L7
L27	Refuse Chamber	L7
L28	External Drainage Work	L7
L29	Road Work	L17
L30	Main Entrance Gate	L29
L31	Site Clearing Work	L30